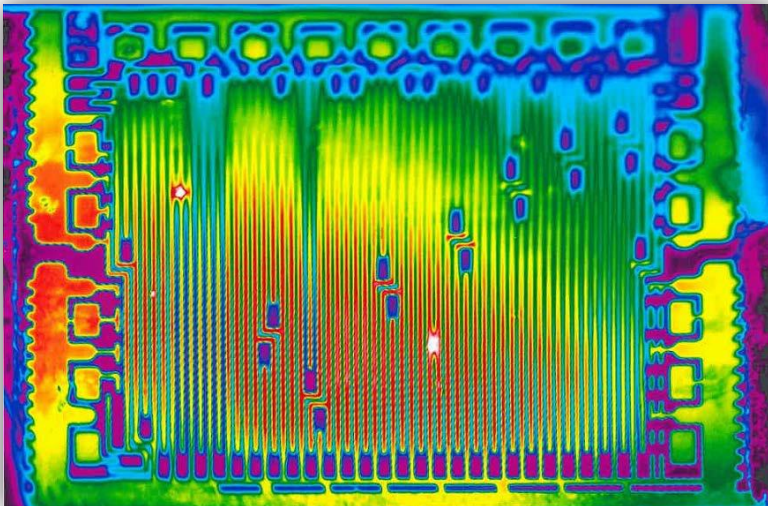




# A Screening Method Using Infrared Imaging to Detect Pattern Defects in Foil and Thin Film Resistors



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# Acronyms

Al-N = aluminum nitride

InSb = Indium Antimonide

NEPP = NASA Electronic Parts & Packaging (NEPP) Program

NiCr = Nichrome

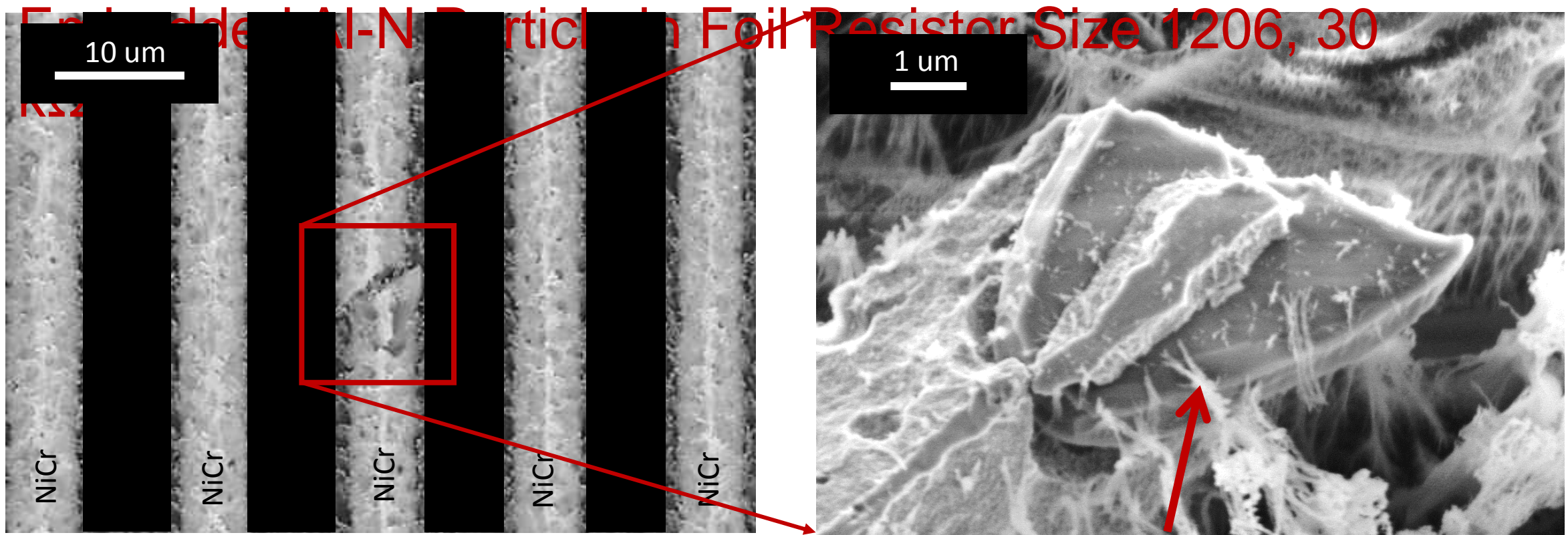


# A Case for an Improved Screening Method:

## System-Level Resistor Failure

- During system-level testing, a NASA program experienced an intermittent open circuit failure of a surface mount Nichrome (NiCr) foil resistor
- Failure analysis identified a fracture in the resistor foil with a non-conductive aluminum nitride (Al-N) particle embedded in the NiCr foil at the failure site
- The particle significantly reduced the cross sectional area of the resistor line leading to 'hot spot' generation during powered operation
  - Power cycling lead to thermomechanical fatigue fracture of the localized constriction
- *Standard part-level screening practices (e.g., short time overload) failed to detect this flawed resistor*

# A Case for an Improved Screening Method:



Fractured NiCr Gridline With Embedded Al-N Particle

Aluminum Nitride Particle

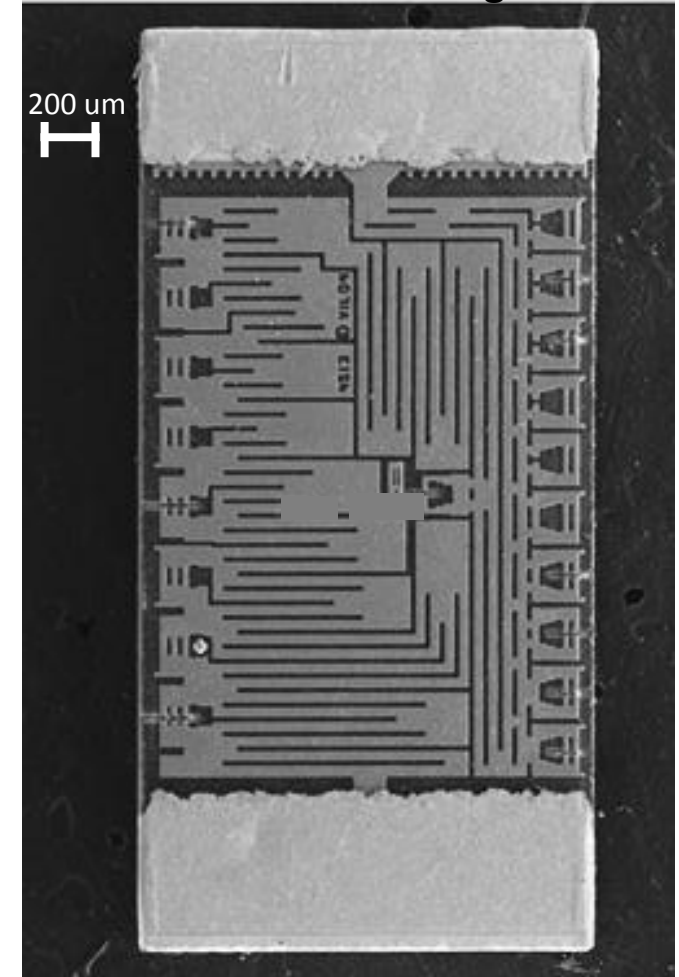
# Basic Construction of the Resistor Element



## Foil Resistors

- **Resistor Material**
  - NiCr-based alloy is rolled into foil sheets
  - Foil thickness is typically 2 – 5 microns
- **Photolithography**
  - Serpentine patterns are etched into the nichrome foil sheet
  - Etched line widths may be as narrow as a few microns.
  - Resistor pattern consists of series and parallel resistor segments
  - Trim tabs built into pattern allow precise resistance adjustment
- **Bonding Resistor Element to Substrate**
  - NiCr foil is adhesively bonded to an alumina substrate
- **Trimming to Value**
  - Laser (or mechanical scribe) is used to selectively cut trim tabs
- **Protective Coatings**
  - Polymeric coatings encapsulate the resistor element

Foil Resistor with  
External Protective Coatings Removed

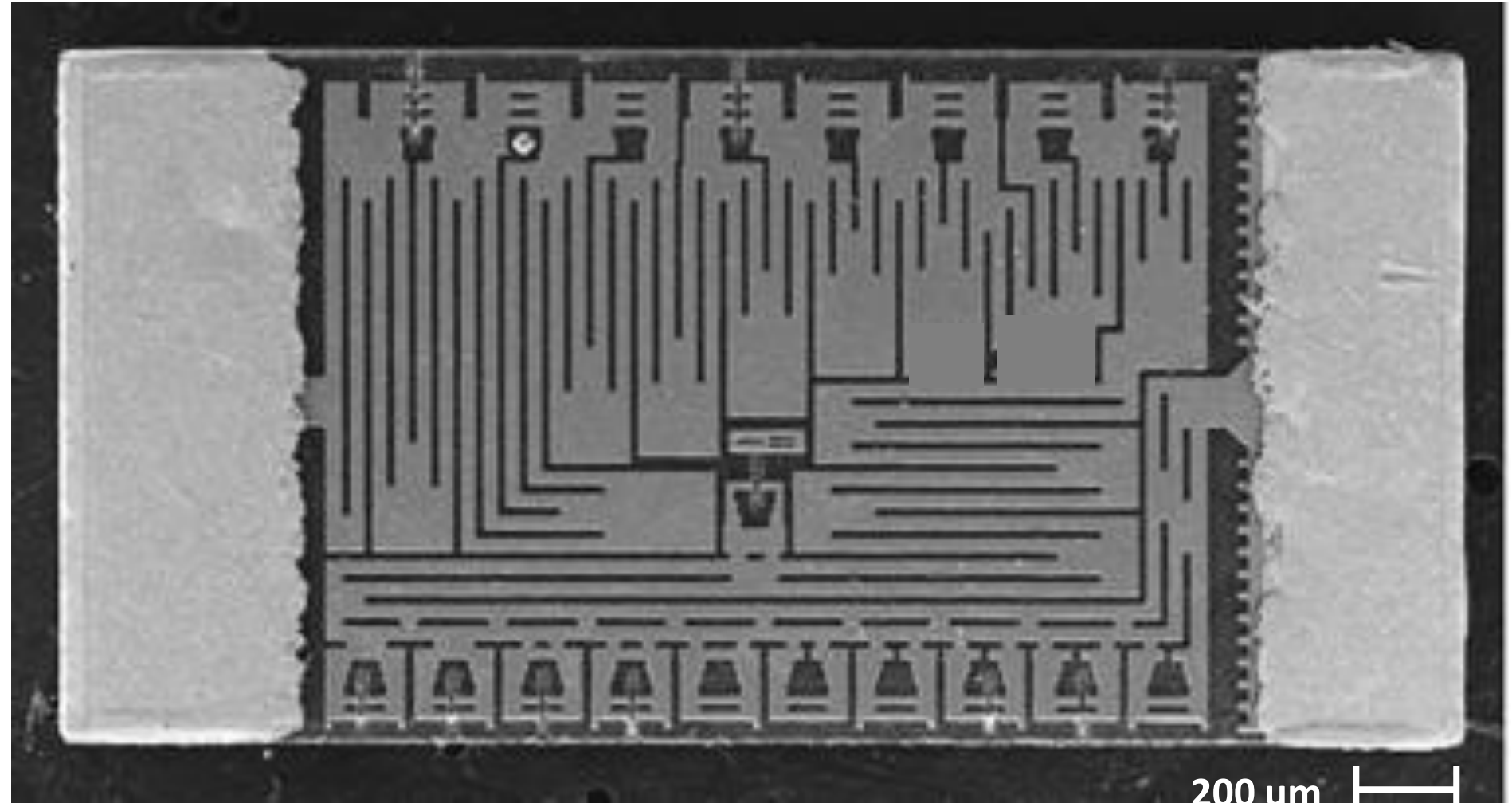


# Basic Construction of the Resistor Element

## Foil Resistors

Size 1206  
49.9 ohms

Low Values  
Have Wider  
Gridlines

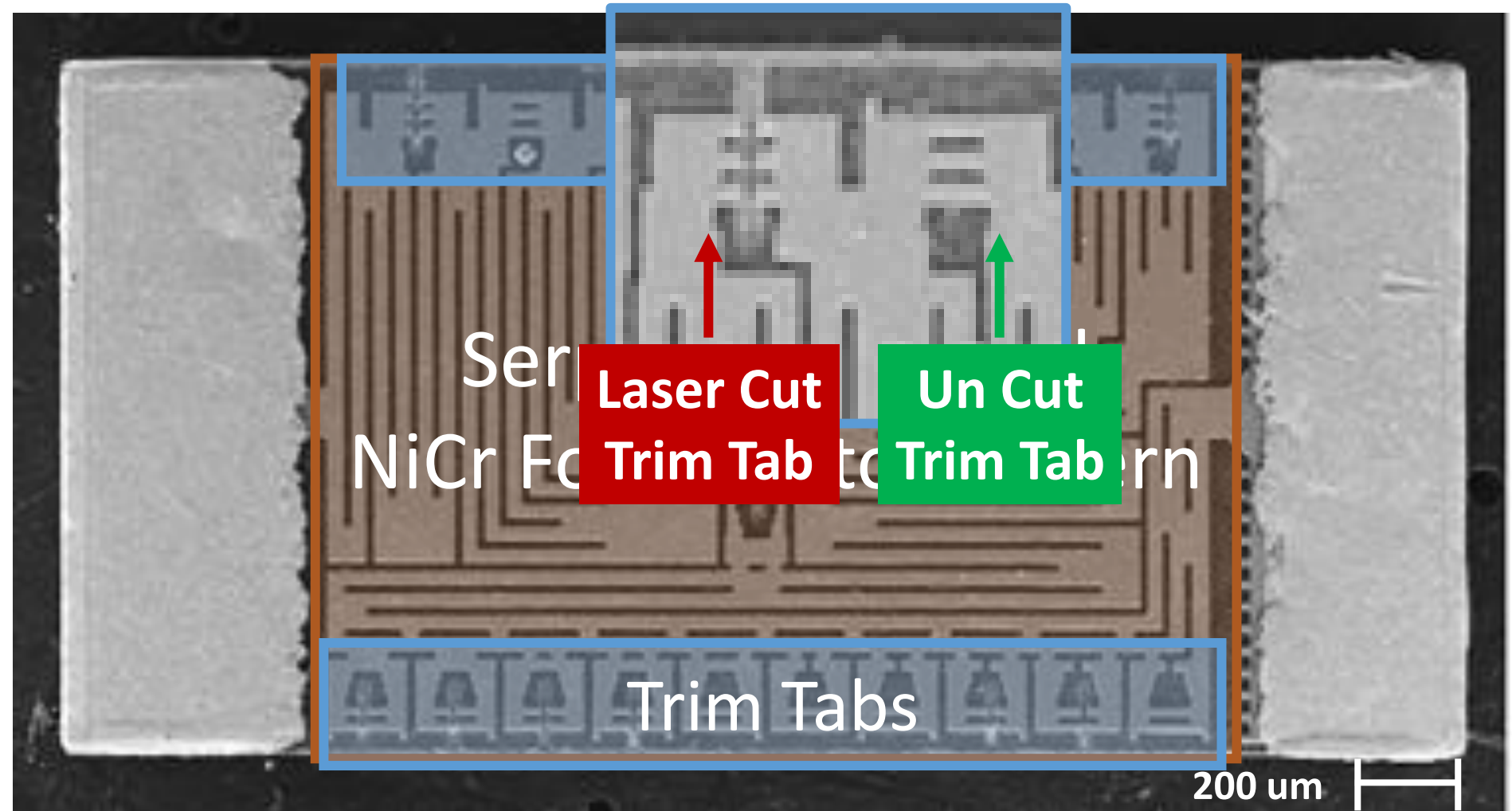


# Basic Construction of the Resistor Element

## Foil Resistors

Size 1206  
49.9 ohms

Low Values  
Have Wider  
Gridlines

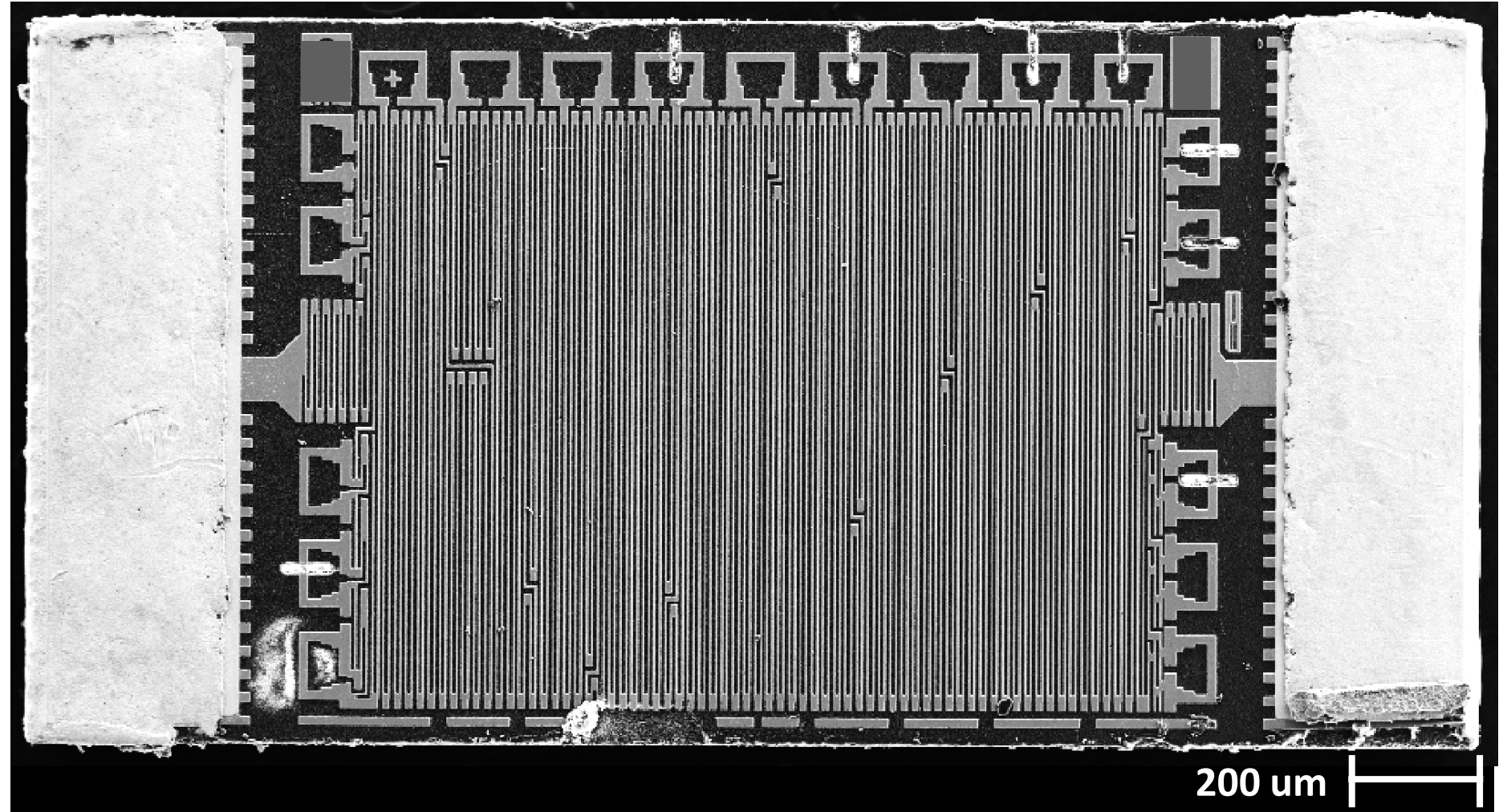


# Basic Construction of the Resistor Element

## Foil Resistors

Size 1206  
20,000 ohms

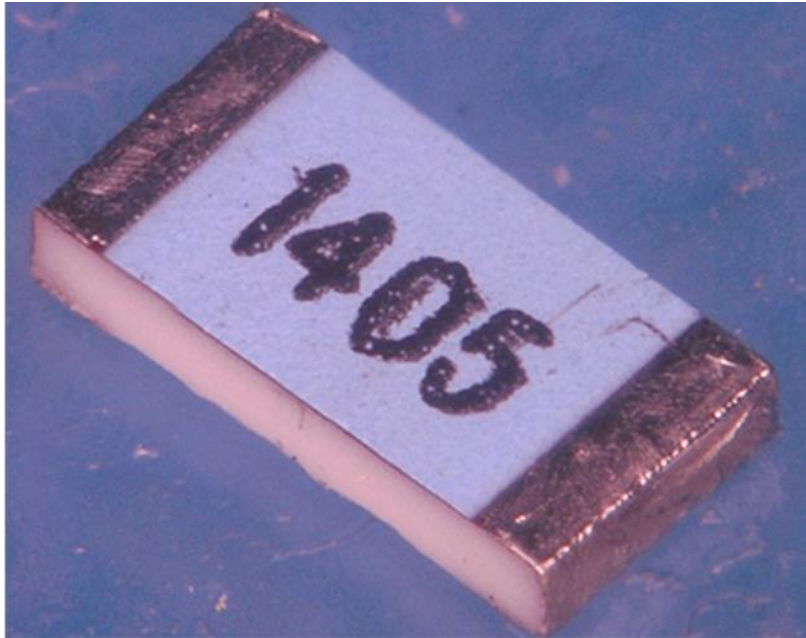
High Values  
Have Narrower  
Gridlines



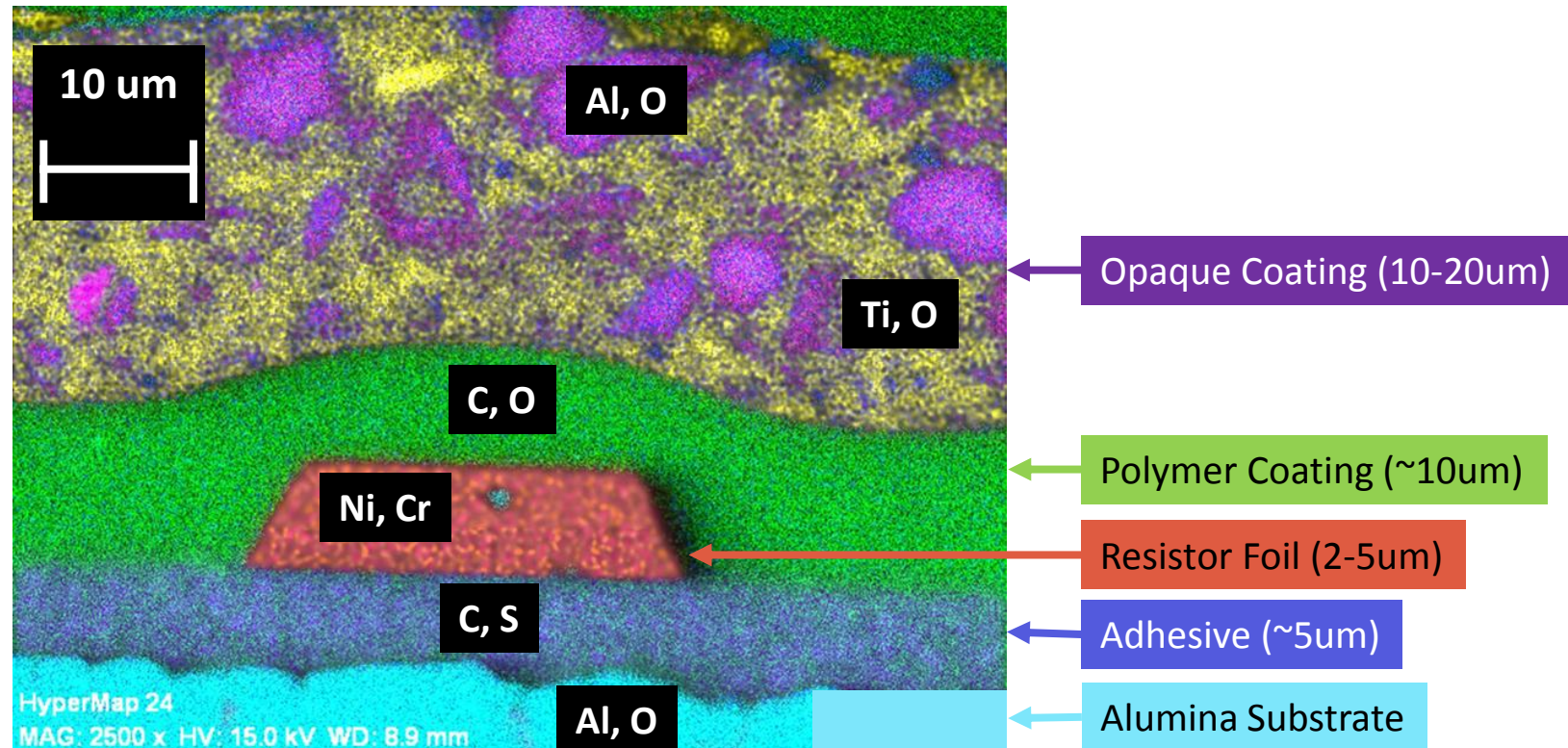
# Basic Construction of the Resistor Element

## Cross Section of a Surface Mount Foil Resistor

### Overview



### Cross Section



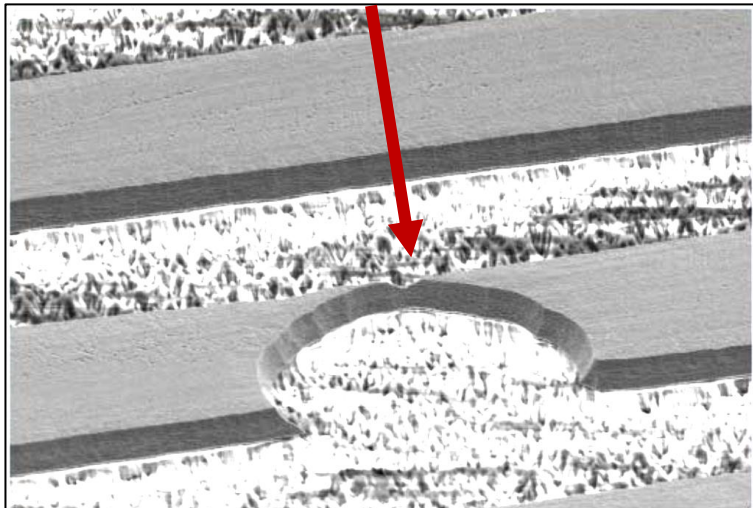
# Traditional Resistor Screening Methods

## Optical Microscopy

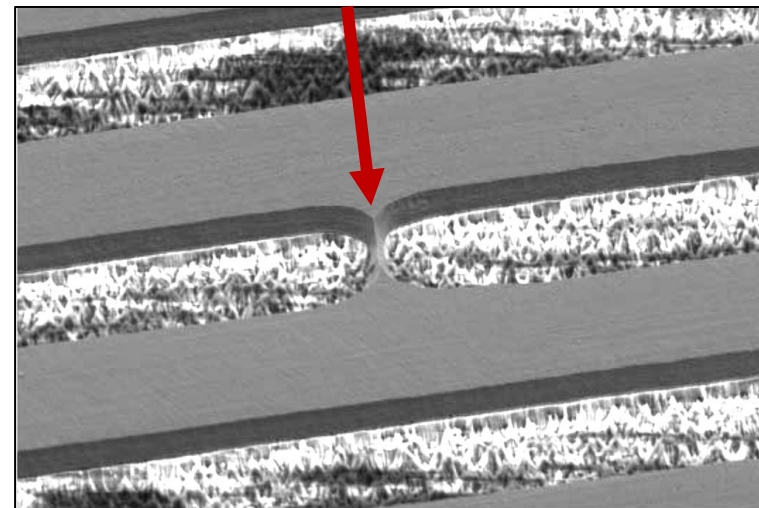


	Thin Film (MIL-PRF-55342)	Foil Resistors
Test Conditions	30x to 60x optical microscopy prior to encapsulation	
Sample Size	100% in-process screen	100% high reliability products only
Rejection Criteria	Voids > 50% nominal line width Bridges < 50% smallest line width	Voids > 75% nominal line width Bridges < 10% smallest line width

**Void > 75% in Foil Resistor**



**Bridge < 10% in Foil Resistor**





# Traditional Resistor Screening Methods

## Short Time Overload

	Thin Film (MIL-PRF-55342)	Foil Resistors
Test Conditions	6.25x rated power for 5 seconds	
Sample Size	20 pcs (space level only)	10 pcs (high reliability products)
Rejection Criteria	$\Delta R > 0.1\%$	$\Delta R > 0.02\%$

*It is claimed that this test will force failure of devices with the most severe pattern constrictions*



# Traditional Resistor Screening Methods

## Power Conditioning (Also referred to as Burn-In)

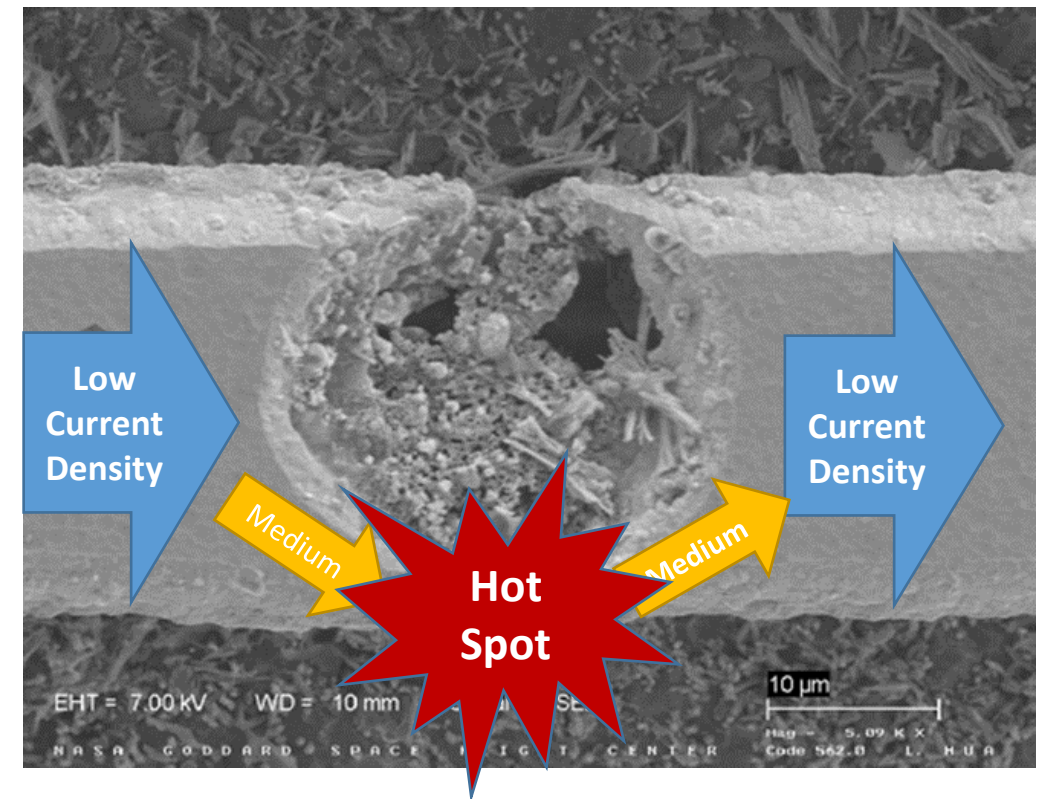
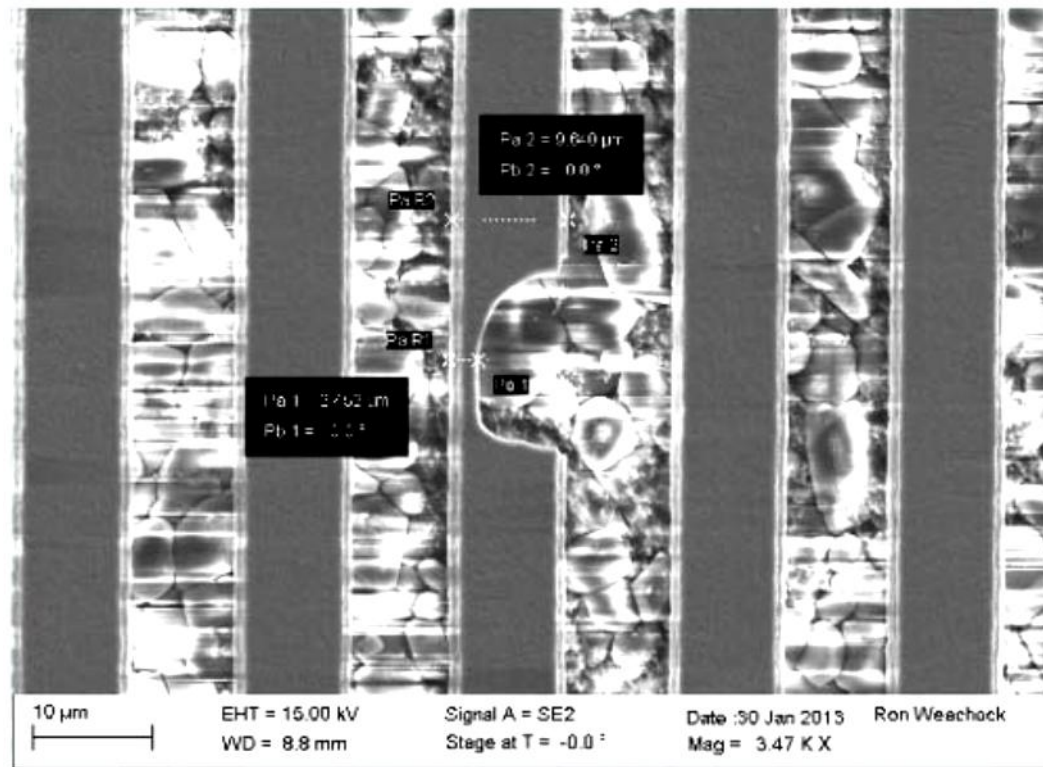
	Thin Film (MIL-PRF-55342)	Foil Resistors
Test Conditions	1.5x rated power for 100 hours at 70°C	
Sample Size	100% (space level only)	100% (high reliability products only)
Rejection Criteria	$\Delta R > 0.2\%$	$\Delta R > 0.03\%$

*It is claimed that this test will force failure of devices with the most severe pattern constrictions*

# Resistor Pattern Defects

## Constrictions (Voids)

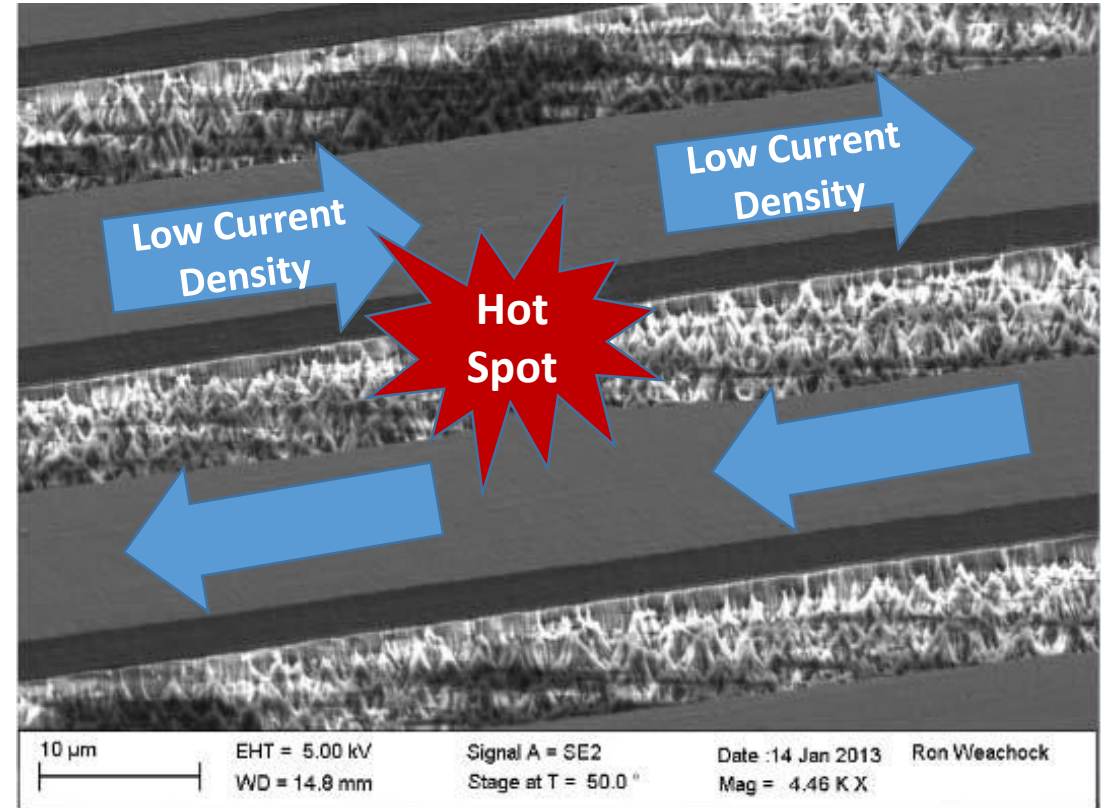
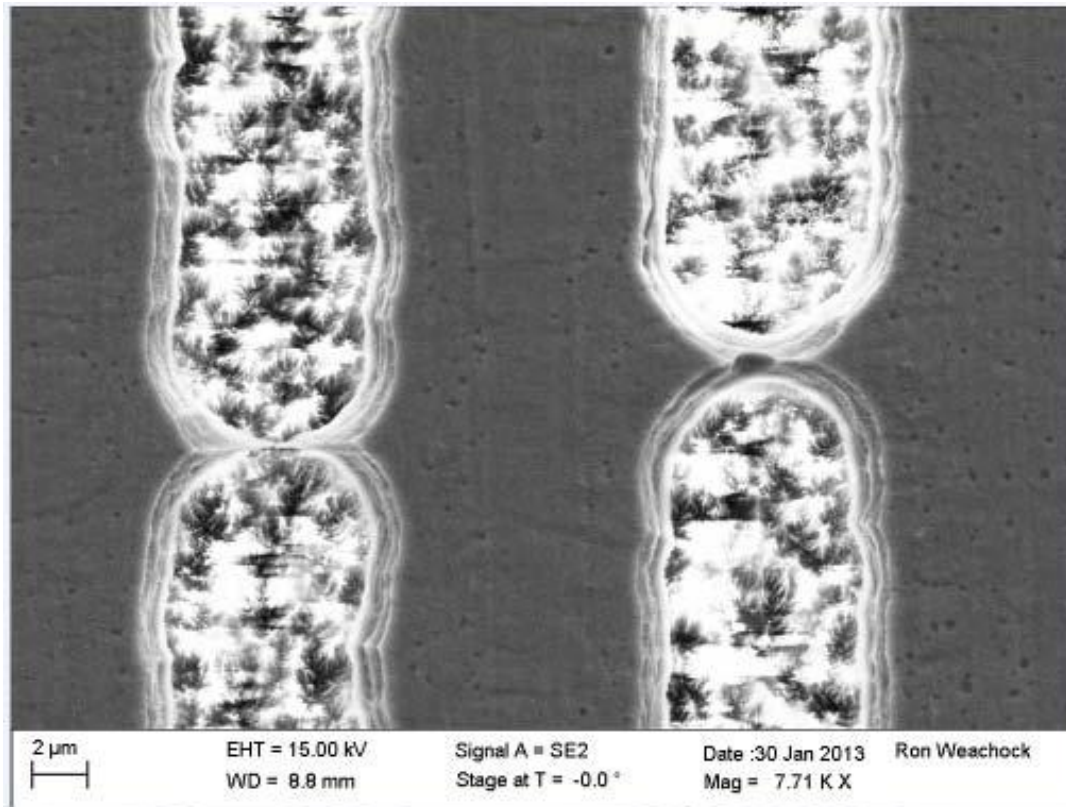
Resistors with these Defects Found By End User Despite Having Been Subjected to Traditional Screening



# Resistor Pattern Defects

## Narrow Bridges

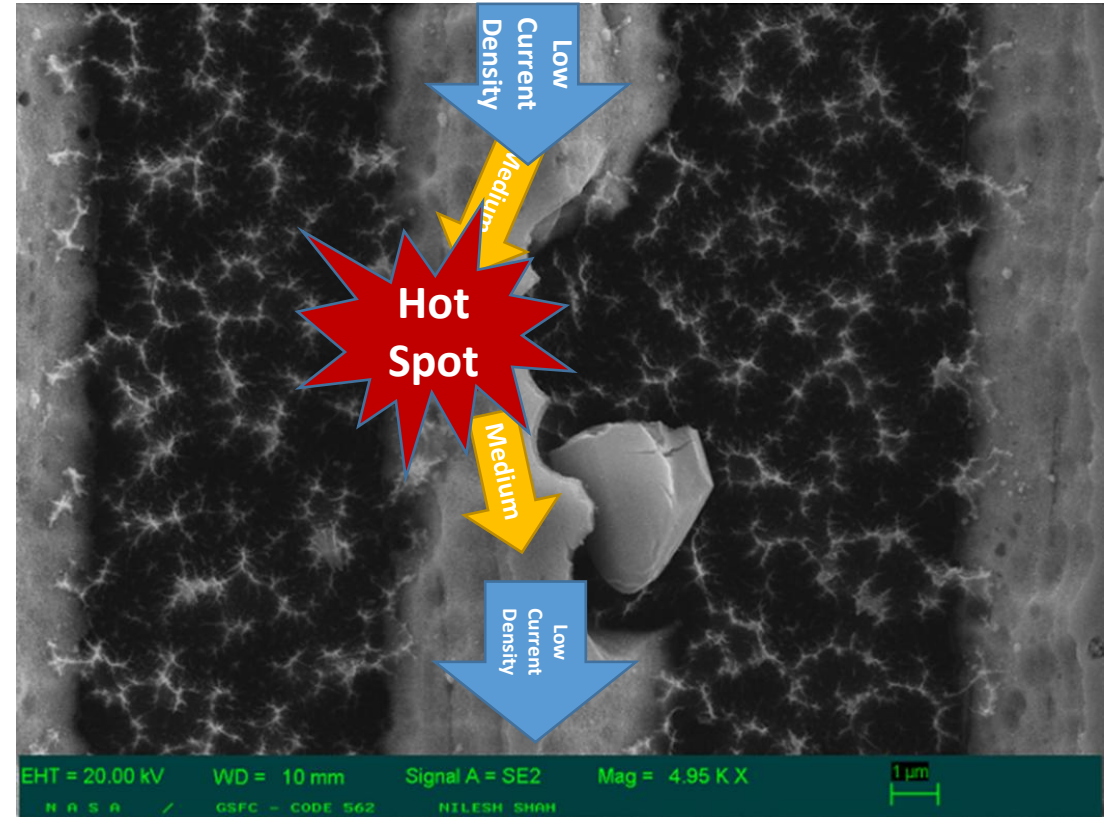
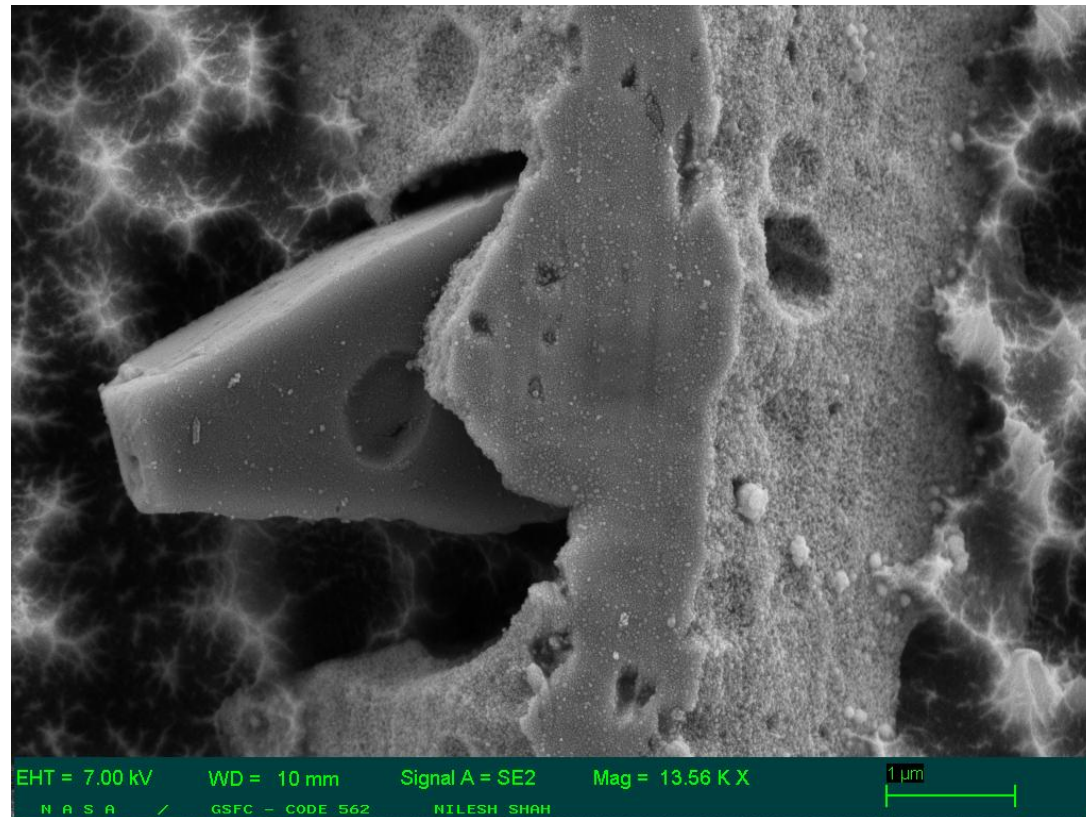
Resistors with these Defects Found By End User Despite Having Been Subjected to Traditional Screening



# Resistor Pattern Defects

## Embedded Particles

Resistors with these Defects Found By End User Despite Having Been Subjected to Traditional Screening





# Resistor Pattern Defects

## Potential Effects of “Constrictions” in Resistor Lines

- Localized constriction in the resistor pattern will result in higher current density and ‘hot spot’ formation due to Joule heating during powered operation
- Localized constrictions are more prone to fracture especially during power cycling
  - *Failure Mechanism* = *thermomechanical fatigue fracture*
  - *Failure Modes* = *open circuit or shift in resistance*
- ‘Hot spots’ can also cause thermal decomposition of protective coatings and adhesives ( $> \sim 300^{\circ}\text{C}$ ) whose byproducts may accelerate failure
  - *Failure Mechanism* = *stress corrosion cracking of resistor element + thermomechanical fatigue fracture*
  - *Failure Mode* = *open circuit or shift in resistance*

# Resistor Pattern Defects

## A Model of Joule Heat Propagation at Local Constriction

### Thermal Diffusion

The Length (L) that a thermal pulse spreads from its origin in time (t) is:

$$L = \sqrt{(D * t)}$$

where D is the thermal diffusivity of the material.

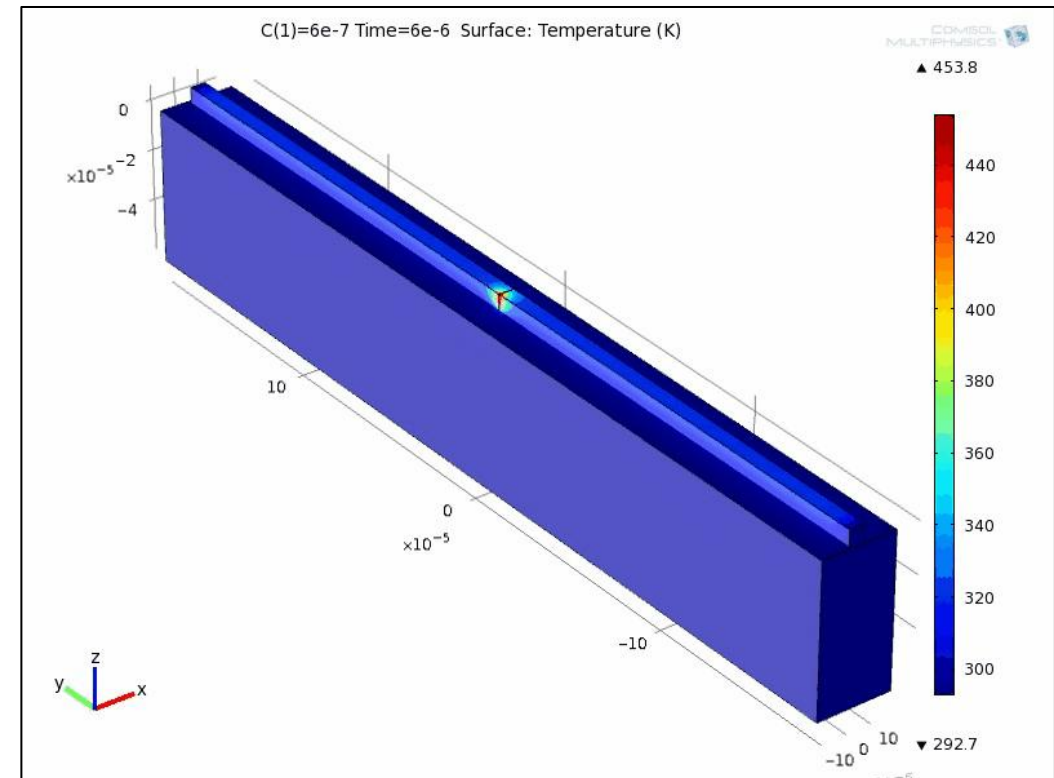
$$D(\text{copper}) \sim 1.2 \text{ cm}^2/\text{s};$$

$$D(\text{nichrome}) \sim 0.11 \text{ cm}^2/\text{s}$$

For example, the distance the pulse spreads in 50 ms is

$$L = 0.074 \text{ cm} = 0.74 \text{ mm}.$$

### Simulated Slice in Resistor Line Reducing Width by 90% (i.e. 10% remaining)



# New Screening Method for Resistor Pattern Defects



## ***High Resolution Infrared Thermography During Power Pulsing***

1. Examine resistor using high resolution infrared camera able to resolve features  $\sim 10$   $\mu\text{m}$  or smaller
2. Apply brief power pulses (a few pulses are sufficient)
  - For example, 6.25x rated power, 50 ms, 10% duty cycle
  - Brief pulses dynamically confine the Joule heating to the “local constrictions” in the pattern
  - Brief duty cycle allows resistor to cool to ambient conditions before subsequent pulse
3. Analyze infrared images for localized “hot spots” within the pattern
  - Hot spots are indicative of constrictions (e.g., voids, bridges, embedded particles)
4. A conservative criteria:  
*Reject parts exhibiting significant “hot spots”*

# New Screening Method for Resistor Pattern Defects

## High Resolution Infrared Camera with 4x lens option



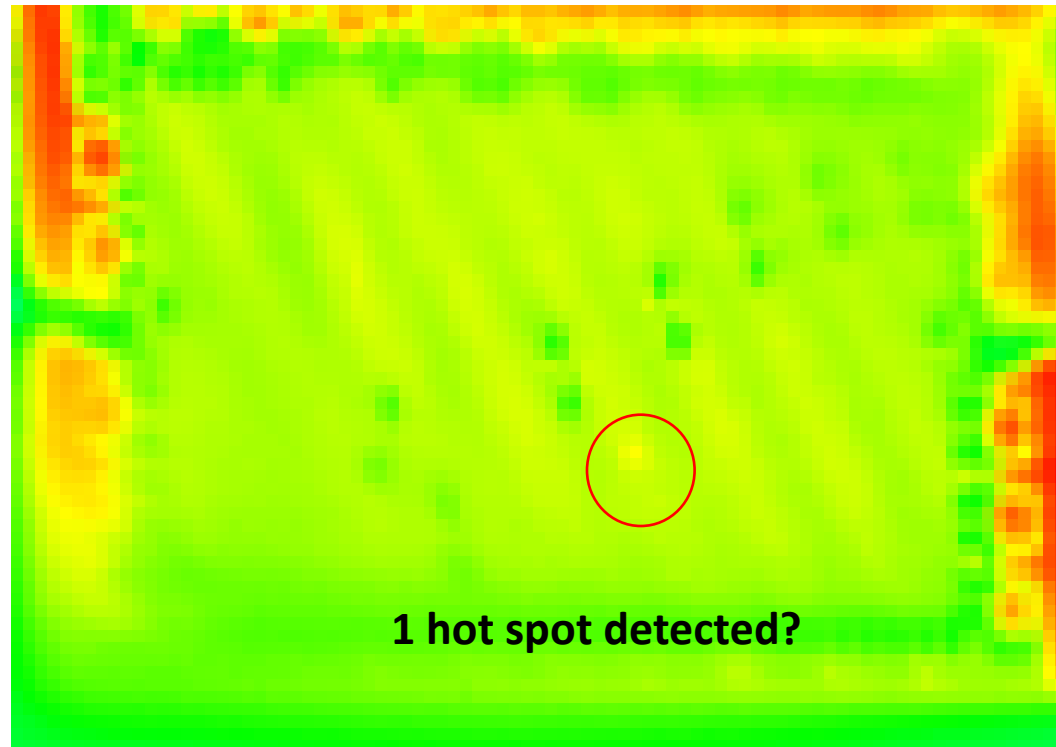
Detector Type	Indium Antimonide (InSb)
Spectral Range	3.0 - 5.0 $\mu\text{m}$
Resolution	$\sim 4\mu\text{m}$
Frame Rate	Up to 132 Hz (frames per second)
Standard Temperature Range	-20°C to 500°C (-4°F to 932°F)
Accuracy	$\pm 2^\circ\text{C}$ or $\pm 2\%$ of Reading

# New Screening Method for Resistor Pattern Defects

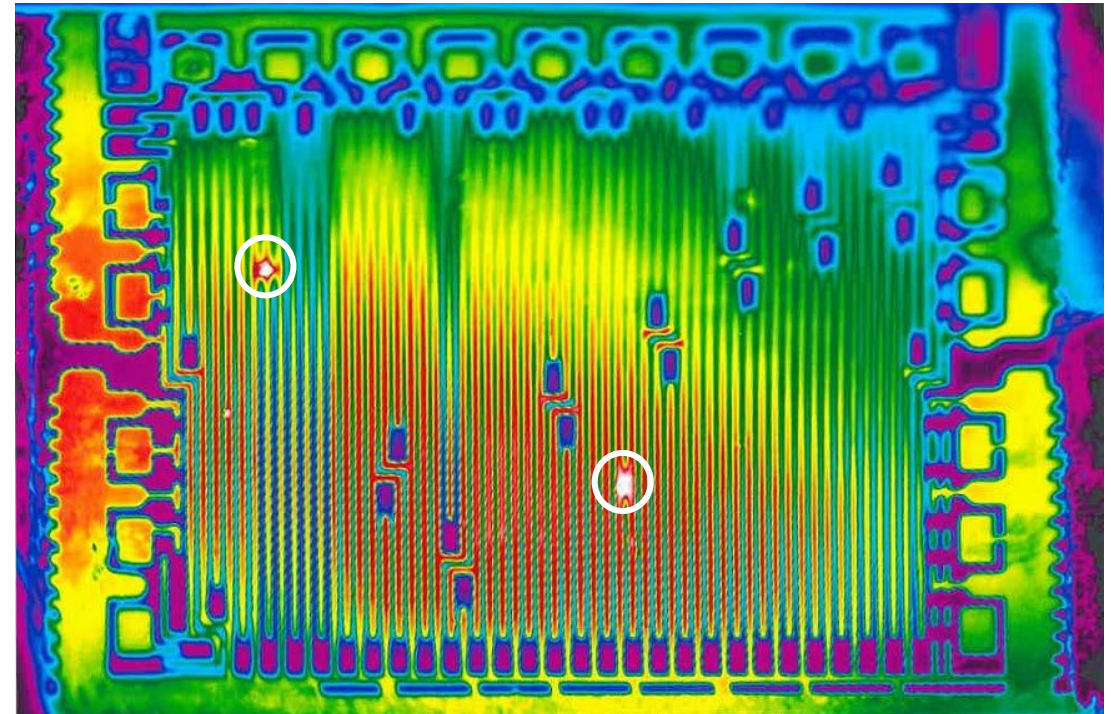


Comparison of Two Different Infrared Cameras  
*The same resistor having 2 constriction defects is examined*

FLIR SC660 with 25 micron detector pitch



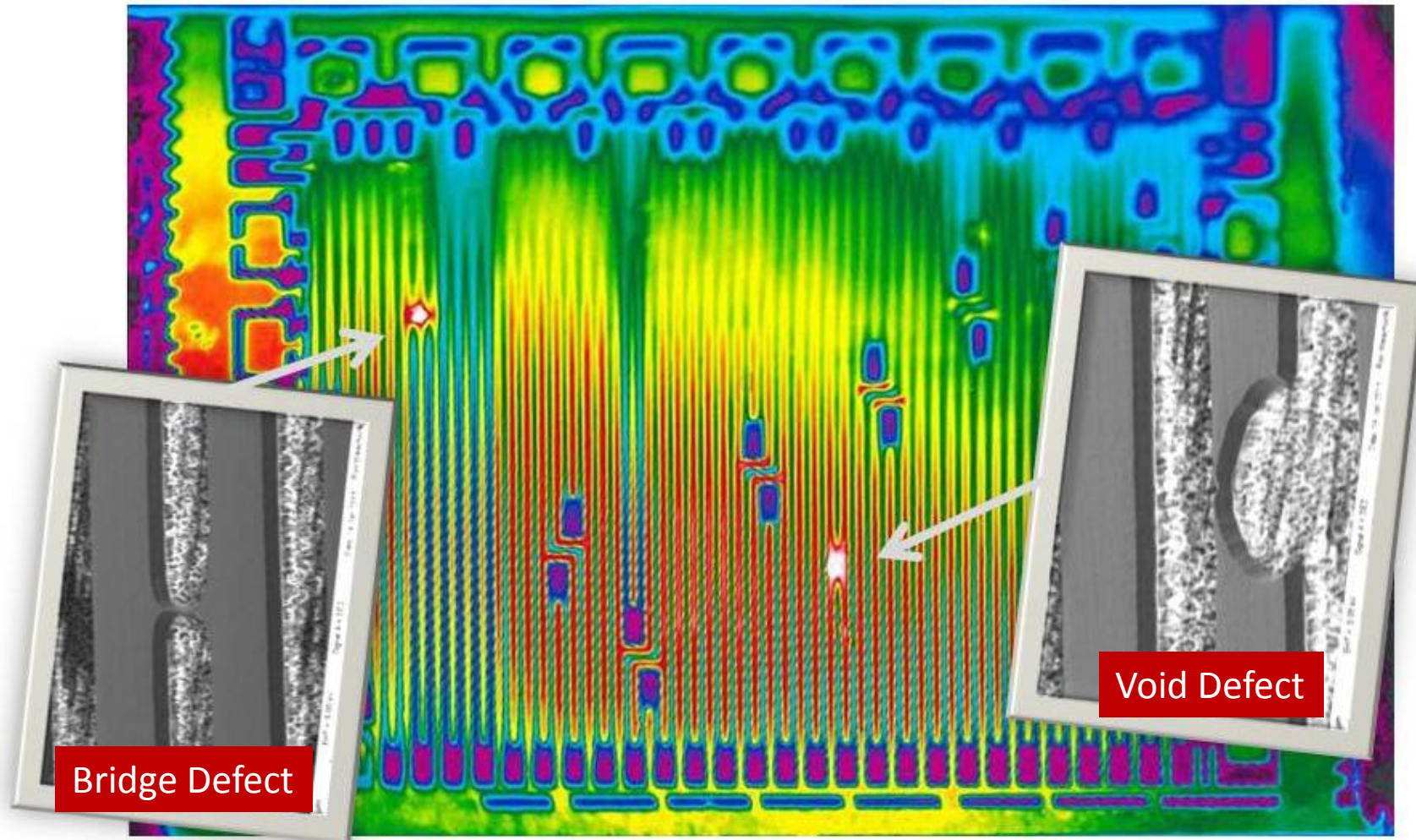
FLIR SC8300HD with 4 micron detector pitch



# New Screening Method for Resistor Pattern Defects



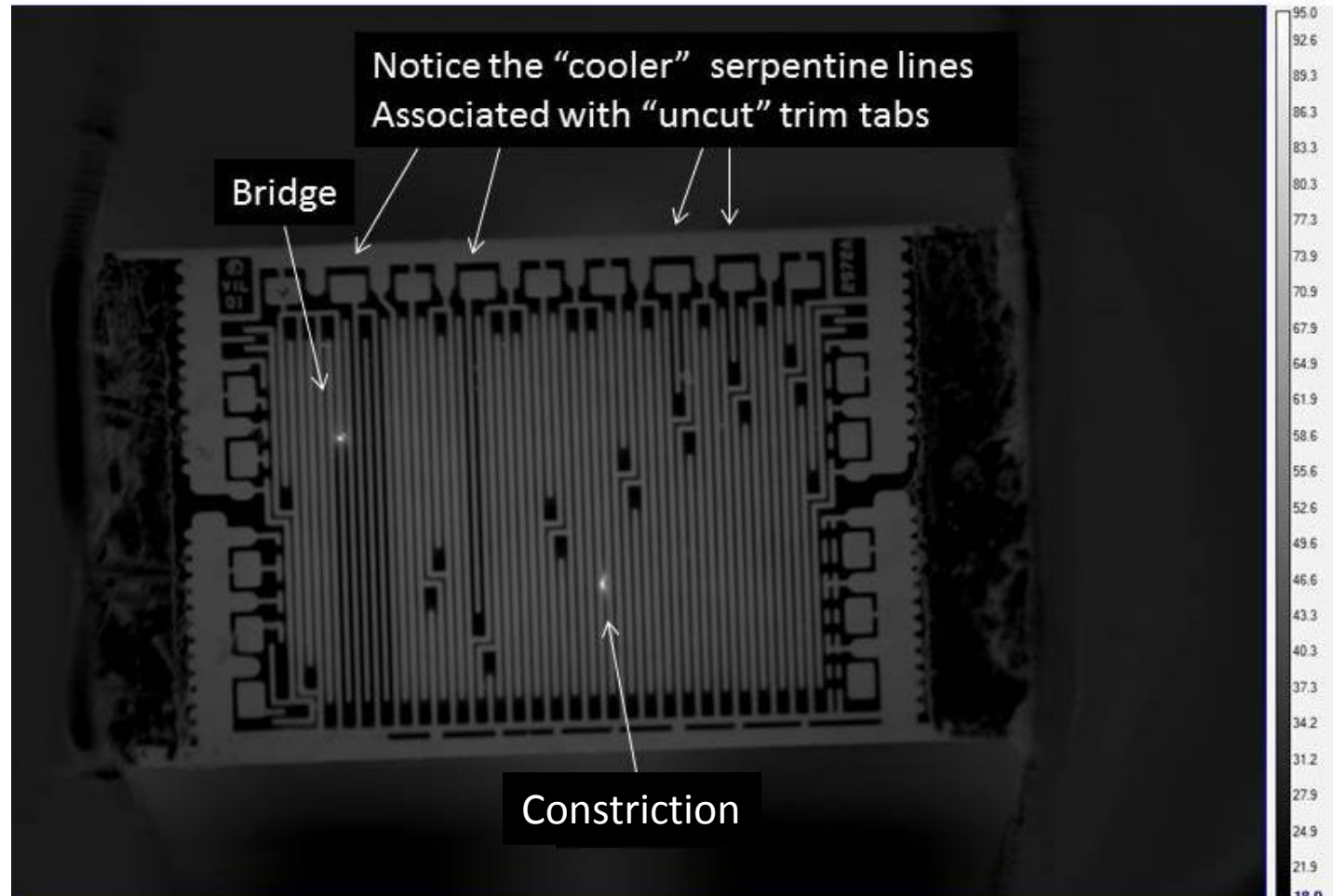
High Resolution Infrared Camera Identifies Hot Spots During Powered Operation



Presented by Lyudmyla Panashchenko at the 2015 Components for Military and Space Electronics (CMSE) Conference and Exhibition, Los Angeles, CA, March 1-3, 2015.

# Infrared Video Demonstration

2k $\Omega$  Foil Resistor; Size 1206; Ten 50 ms pulses at 6.25x Rated Power



# New Screening Method for Resistor Pattern Defects

The Protective Coatings are Transmissive at These Infrared Wavelengths

This feature enables use of this technique as a post-procurement screening inspection

## Optical Image

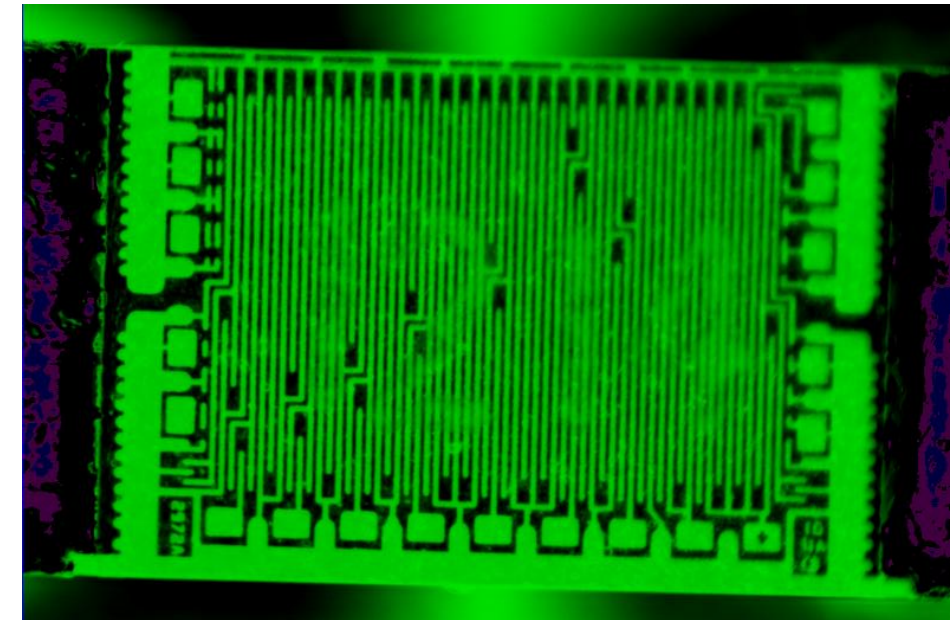


Infrared Image of  
*UNPOWERED*  
Resistor



## Infrared Image

Using FLIR SC8300 Camera with  
spectral range 1.5 to 5.0 microns

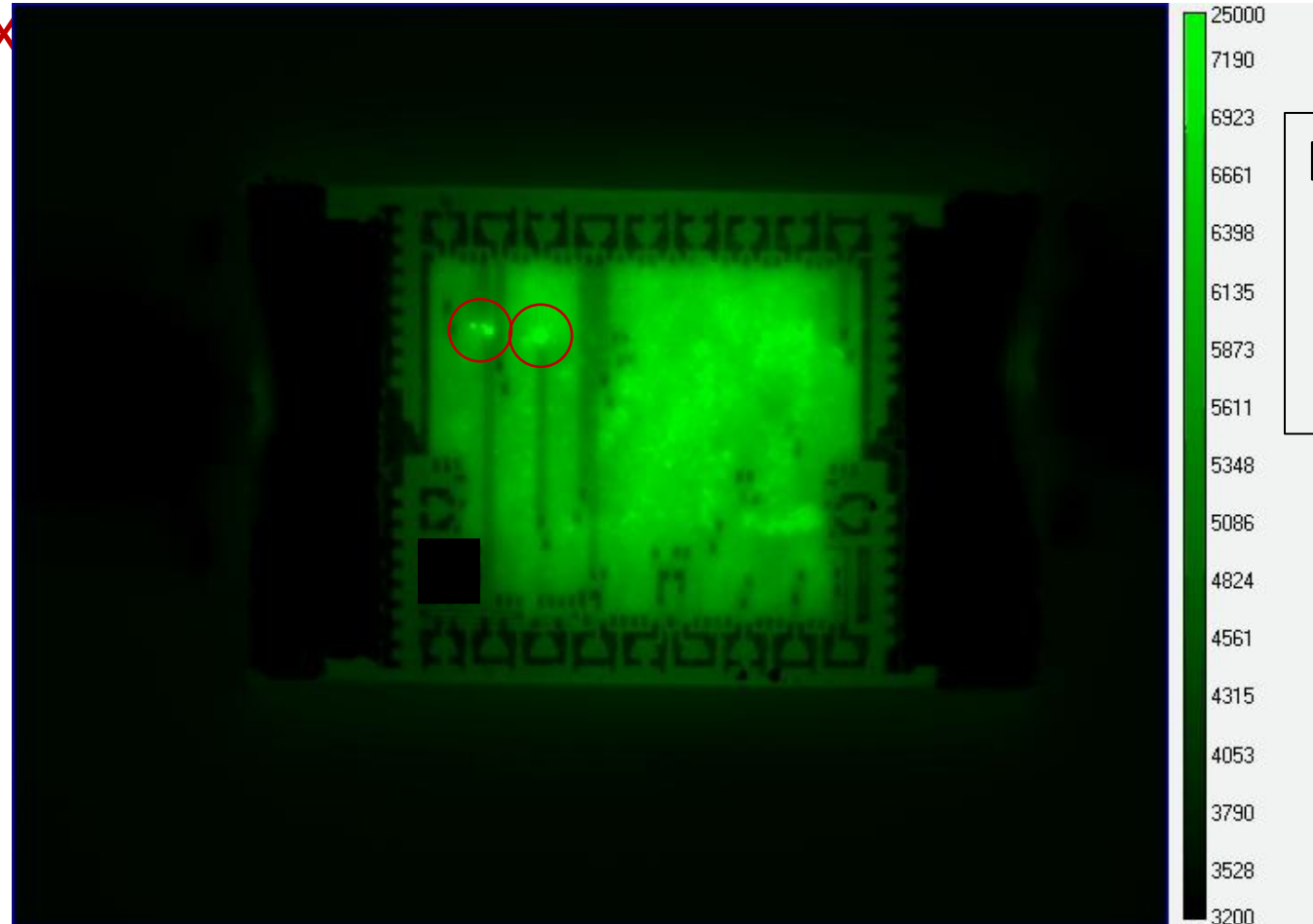


# Example Inspection with New Method



## Foil Resistor with Multiple Bridge Defects as Seen in Infrared

Applying 6.25x

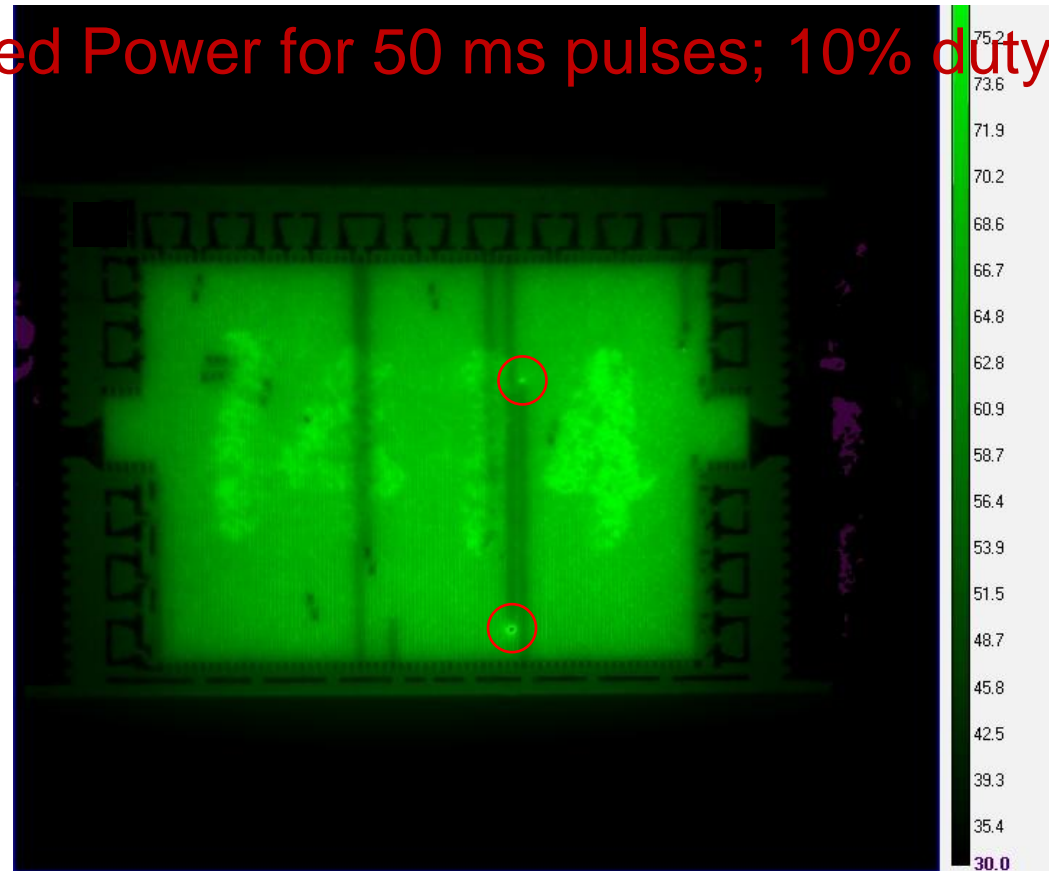


**Inspection Performed  
Without Removing  
Resistor Protective  
Coatings**

# Example Inspection with New Method

## Foil Resistor with Two Bridge Defects as Seen in Infrared

Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle



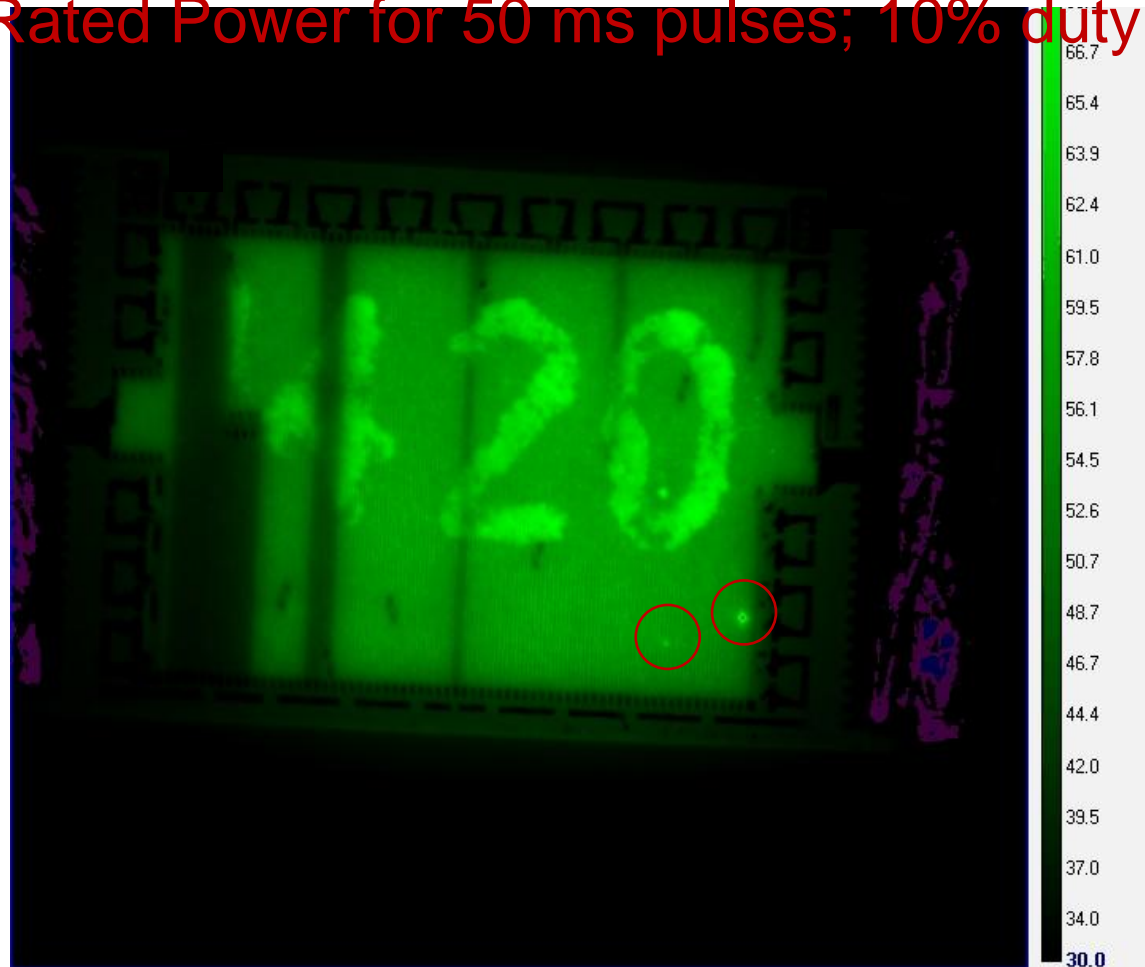
**Inspection Performed  
Without Removing  
Resistor Protective  
Coatings**



# Example Inspection with New Method

## Foil Resistor with Two Local Constriction Defects as Seen in Infrared

Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

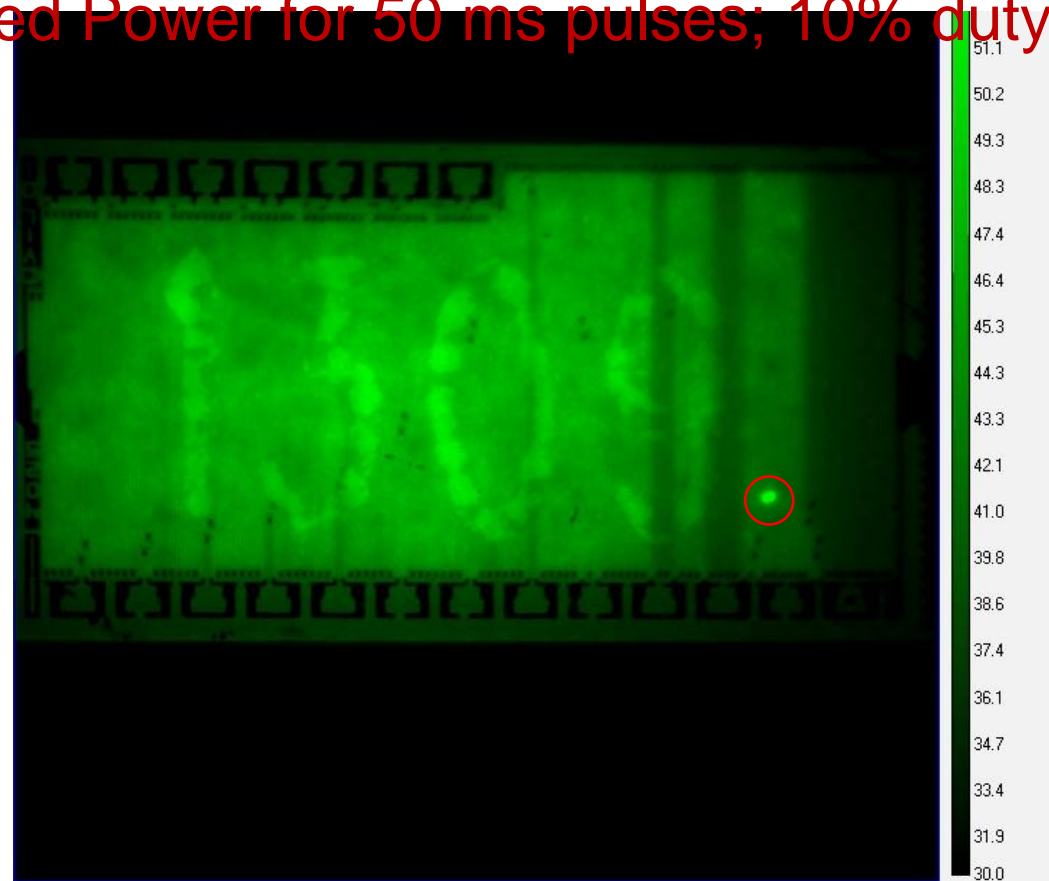


**Inspection Performed  
Without Removing  
Resistor Protective  
Coatings**

# Example Inspection with New Method

## Foil Resistor with One Local Constriction Defect as Seen in Infrared

Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

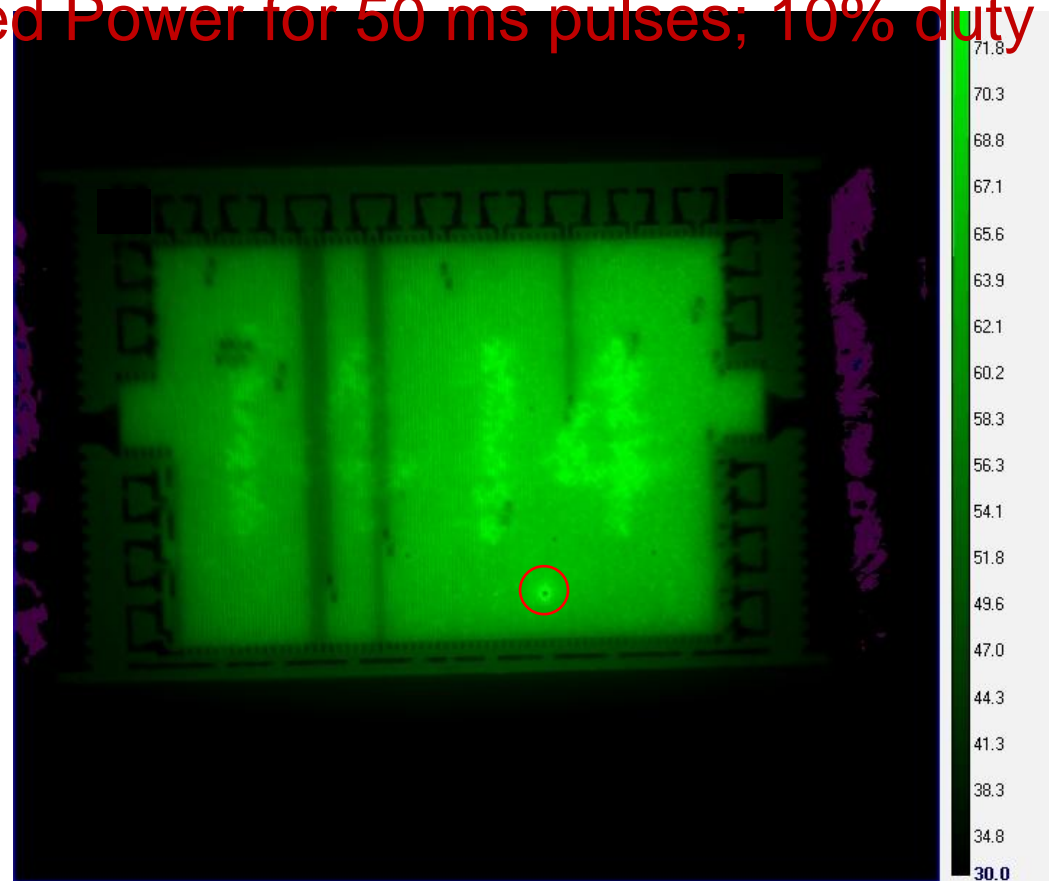


**Inspection Performed  
Without Removing  
Resistor Protective  
Coatings**

# Example Inspection with New Method

## Foil Resistor with One Local Constriction Defect as Seen in Infrared

Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle



**Inspection Performed  
Without Removing  
Resistor Protective  
Coatings**



# Conclusions

- NASA has developed a method to detect pattern defects in foil and thin film resistors using high resolution infrared thermography while applying brief power pulses
- The technique can be used at various stages:
  - In-process screen by resistor manufacturer prior to protective coating application
  - Post-procurement screen by end user if coatings are transmissive at infrared wavelengths
  - Destructive physical analysis and failure analysis

## Future Work

- NASA plans to evaluate reliability of suspect parts identified by this method
  - Long-term life test comparison of suspect vs. non-suspect parts



# Acknowledgements

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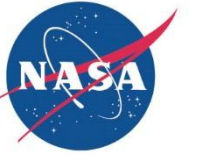
Test Engineer, Arctic Slope Regional Corporation @ NASA-GSFC

[Timothy.K.Mondy@nasa.gov](mailto:Timothy.K.Mondy@nasa.gov)



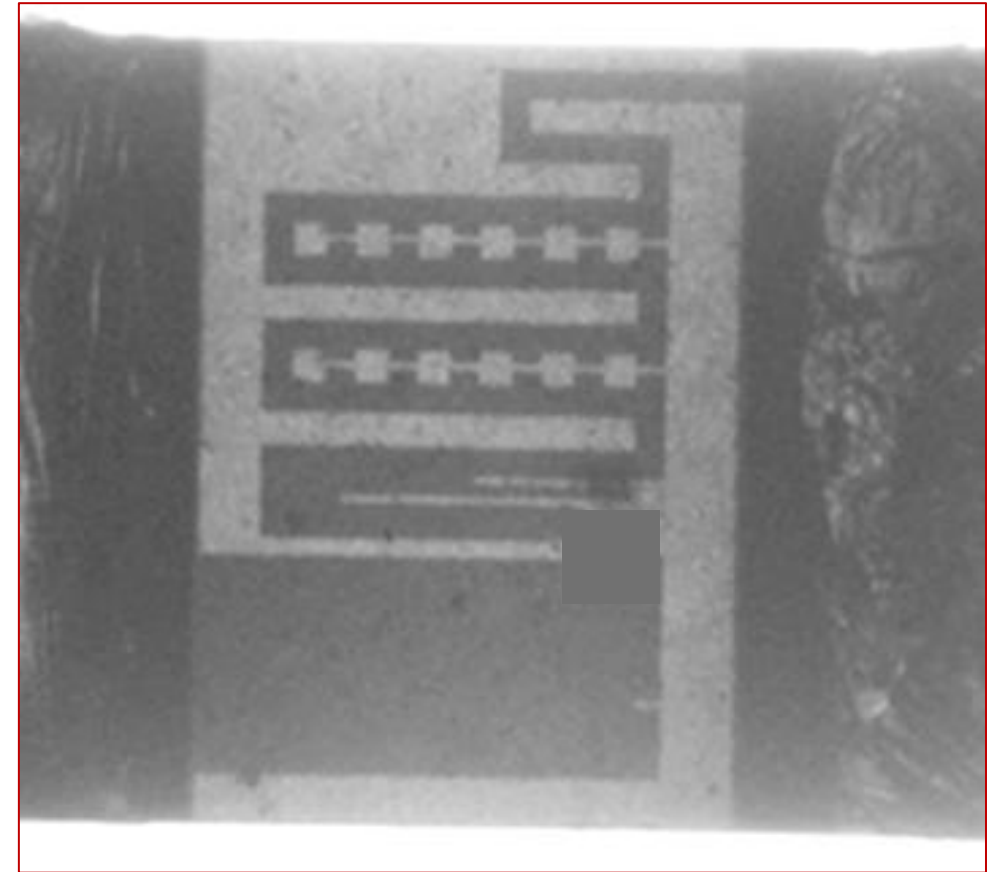
# Backup Slides

# Basic Construction of the Resistor Element



## Thin Film Resistors

- **Resistor Material**
  - Typically a NiCr or Tantalum Nitride-based alloy sputter deposited onto an alumina substrate
  - Film thickness typically 50 nm to 250 nm
- **Photolithography**
  - Serpentine patterns are etched into the thin film
  - Etched line widths as narrow as a few microns
  - Pattern consists of both series and parallel resistor segments
  - Coarse, Intermediate and fine adjustment pattern features are built into the pattern
- **Trimming to Value**
  - Laser is used to selectively remove thin film resistor material
- **Protective Coatings**
  - Polymeric coatings encapsulate the resistor element

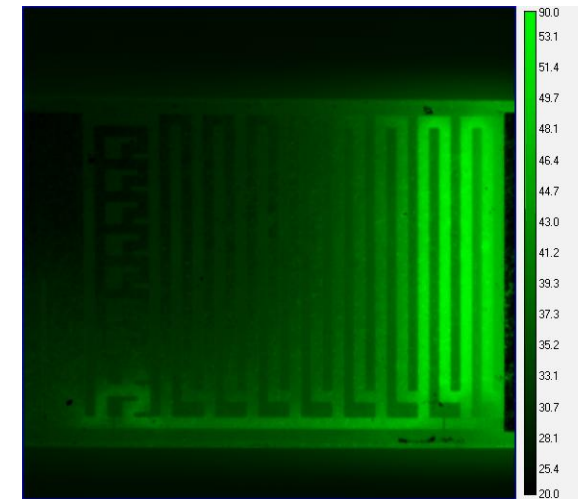
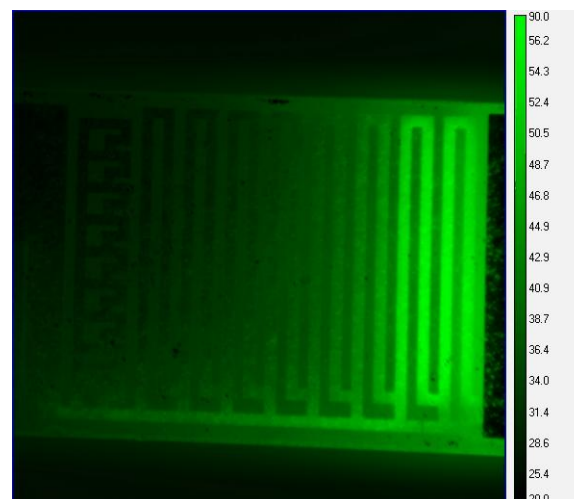
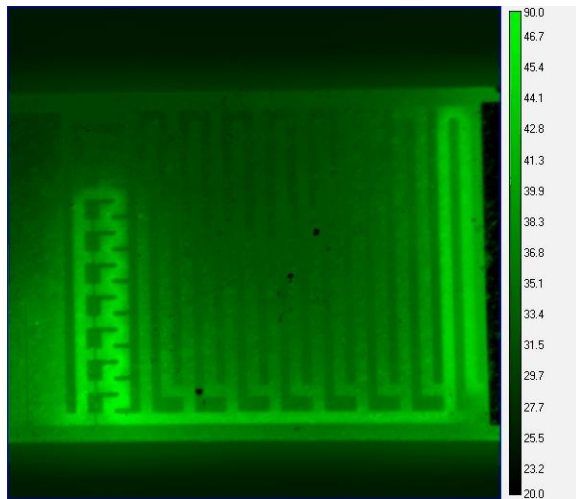


# Example Inspection with New Method

## Thin Film Resistors as Seen in Infrared

Applying 6.25x Rated Power for 100 ms pulses; 10% duty cycle

Inspection Performed  
Without Removing  
Resistor Protective  
Coatings



# Example Inspection with New Method

## Thin Film Resistors as Seen in Infrared

Applying 6.25x Rated Power for 100 ms pulses; 10% duty cycle

Inspection Performed  
Without Removing  
Resistor Protective  
Coatings

